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Costs and Quality of Water in Ohio Cities

MICHAEL H. COSGROVE and LEROY J. HUSHAK

OHIO AGRICULTURAL RESEARCH AND DEVELOPMENT CENTER
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Costs and Quality of Water in Ohio Cities[1]

MICHAEL H. COSGROVE and LEROY J. HUSHAK[2]

INTRODUCTION

The purpose of this study is to estimate cost functions for public water systems in Ohio cities. The specific objective is to estimate the relationships among the costs of water systems and the quantity and quality of water. This requires the development of measures of input and output water quality, in addition to a measure of quantity. The analysis concentrates on the cost-quantity and cost-quality partial relationships within the estimated equations.

In concentrating on cost functions of public water systems, this study is only one part of the problem of costs and benefits of public water systems. The benefits of water systems are not investigated; neither are the tradeoffs between public water system costs and the costs of reducing water pollution by other methods, e.g., increased purification of waste water. This study concentrates on the technical cost relationships of city water systems.

Public water systems and water production are discussed first. Then a theoretical model for water cost functions is developed. Next, the variables for which data are available and the mathematical forms of the estimating equations are defined. Estimated variable and total cost functions are analyzed in the next two sections. The study is summarized and conclusions are drawn in the final section.

PUBLIC WATER SYSTEMS

Public water systems in the United States numbered 19,236 and served about 150 million people when last inventoried in 1963. Approximately 50 million people had private water supplies. Most of the public systems were small, with about 85 percent serving 5,000 or fewer people. Of the people served by public water systems, about one-half (77 million) were served by 399 systems each serving more than 100,000 persons, and the other one-half were served by 18,837 smaller systems. About 75 percent of these systems had ground water as a source, while 18 percent used surface water. The remaining 7 percent used a combination of ground and surface water (9, page 11).

Ohio ranks sixth in total water use among the 50 states. Only one other eastern state, Pennsylvania, uses more. The other four leading water-using states are in the West, where large quantities are required for irrigation. Industrial water use in Ohio is the highest in the nation (4, page 2).

The first public water system in Ohio was constructed in 1821 in Cincinnati, which had a population of about 10,000. Steubenville, with 4,000 inhabitants in 1825, built the second public water supply system. Cleveland built a municipal plant in 1855 to pump Lake Erie water for the use of 30,000 residents. In 1870, when Ohio's population was approximately 2.7 million, there were 11 public water systems.

The 1900's have been a period of rapid increase in public water systems. By decades, the figures are (10, pages 27-28):

1900—172 plants served 2,057,000 inhabitants or 49.6 percent of the population.

1910—237 plants served 2,804,300 inhabitants or 58.9 percent of the population.

1920—277 plants served 3,867,000 inhabitants or 67.1 percent of the population.

1930—319 plants served 4,782,000 inhabitants or 72 percent of the population.

1940—416 plants served 4,962,300 inhabitants or 71.9 percent of the population.

1950—467 plants served 5,676,300 of Ohio's inhabitants or 71.5 percent of the population.

1960—529 plants supplied water for 181 cities and 497 Ohio villages. These 672 municipalities contained 7,088,916 inhabitants or 73.5 percent of the population.

In 1970, an estimated 680 plants served approximately 81 percent of the population.[3]

In 1965, total water use per day in Ohio amounted to nearly 12 billion gallons, which is 1,200 gallons per person per day. The breakdown by use is shown in Table 1. Public systems distribute approximately 1 billion gallons per day, which is 167 gallons per person. In the average city, 53 out of every 100 gallons from public systems are used by industry, 39 gallons by residents, 6 gallons by commercial establishments, and 2 gallons by fire departments and miscellaneous users.

[1]This study is based on a Ph.D. dissertation completed by Michael H. Cosgrove under Hatch Project 380, Ohio Agricultural Research and Development Center (1).

[2]Former Graduate Associate and Assistant Professor, respectively, Department of Agricultural Economics and Rural Sociology, Ohio Agricultural Research and Development Center and The Ohio State University.

[3]From Robert Shoup, Water Supply Unit, Ohio Department of Health.

TABLE 1.—Inventories of Water Use in Ohio During 1965.

	Millions of Gallons per Day	Percent
Public Supplies	965	8
Domestic and Commercial (705)		
Industry (260)		
Manufacturing (Private Supplies)	2,985	26
Power (Steam)	7,400	64
Rural Uses	222	2
Homes and Livestock (139)		
Irrigation (83)		
TOTAL	11,572	100

Source: Frost (4, page 5).

Water Use and Problems

Traditionally, communities have used quantity as the dimension of water on which to base decisions concerning the development and expansion of water services. However, adverse effects on water quality, because of increased use of water by industry and the growing population, have made the consideration of quality dimensions necessary in addition to the quantity dimension. As a result, communities are giving more attention to the costs and benefits of water quality, both within and outside their boundaries.

Water is used for household, commercial, agricultural, and industrial purposes. The increasing concentration of people and firms in urban areas requires large and increasing amounts of water within small areas. In addition, water use per capita is increasing due to increasing utilization of water-using devices in the home and increasing industrial use (4, page 11). These factors imply a growing demand for water from public water systems in the future.

The problem of supplying users with the appropriate quality of water is becoming more crucial. Many industrial processes can utilize a quality of water similar to that prepared by municipal treatment plants. However, a wide range of quality is required in industrial applications. Cooling water can often be of comparatively low sanitary quality, while water for human consumption must be of high sanitary quality. In terms of overall quantities of water, the use of industrial water for cooling is by far the most important, with approximately 80 percent of industrial water being used for this purpose (6, page 20). The large potential for use of lower quality water by industry may imply one source of water for cooling and a different source for human consumption.

Perhaps the major problem of the future for public water systems is the pollution of water sources from the disposal of wastes (3). The many pollutants which enter water sources as a result of domestic, industrial, and agricultural activities can be grouped in a variety of ways. One classification, useful for this study, divides pollutants into degradable and nondegradable. Degradable pollutants are substances which are changed in form and reduced in quantity by the biological, chemical, and physical characteristics of natural waters. Nondegradable pollutants are not altered by the biological, chemical, and physical processes occuring in natural waters (6, pages 10-13).

Nondegradable pollutants are radiological waste products, persistent organics, inorganic chemicals, and suspended materials. Radioactive elements decay, but the process is usually very slow. The persistent organics, which include many of the organic compounds synthesized by the chemical industry, are classified as nondegradable because they resist attack by stream plant and animal life. Some of the organic chemicals found in surface sources are DDT, 2,4-D, cyanides, and synthetic detergents. Inorganic chemicals, such as the chlorides, are often industrial wastes in the form of metallic salts and other toxic, corrosive, colored, and taste-producing materials.

A final class of nondegradable pollutants is suspended material. These pollutants include silt and other suspended sediments from land erosion and dredging. These suspended materials are nondegradable as they are not changed in form. However, they can be allowed to settle out and usually do not create great difficulties.

Degradable wastes are pollutants which are changed in form by the characteristics of natural water. The most widespread source of such materials is domestic sewage. This highly unstable organic waste is converted into stable inorganic materials by the bacteria and other organisms found in natural water bodies. This process, known as self-purification, proceeds by the action of bacteria utilizing free oxygen as long as the water is not too heavily loaded with sewage. If the receiving waters are loaded with sewage beyond a certain level, the process of self-purification reverses. The bacteria no longer utilize free oxygen and the process takes place anaerobically, with noxious gases such as hydrogen sulfide being produced. As the concentration of people and firms increases, more wastes must be disposed of and, simultaneously, more water is needed for consumption. So one use imposes costs on the other.

Another possible problem is that recreational uses of water may have adverse effects on water quality. If water is used for recreation and human consumption, then recreation may impose costs on water for human consumption. An increasing population, more industry, more waste production, and more leisure cause increasing problems in the delivery of public water to consumers.

Water Production

The public water production process consists of:

1. The selection of the source, which may be underground, surface, or a combination of the two.
2. The movement of water to the processing plant.
3. The subjection to treatment processes designed to improve the physical, chemical, and biological characteristics to make water suitable for human consumption.
4. The storage and distribution to consumers of treated water.

The number and type of treatment processes to which water is subjected depend on the quality of the intake water. When water contains organic substances, it must be treated with chlorine to kill bacteria. When water is corrosive or hard, it may have to undergo softening or other special treatments. Algae may cause undesirable tastes and odors and, when present in large amounts, increase treatment problems. Certain industrial chemicals affect the safety of water supplies. The appeal of drinking water is reduced by color or by foaming which results from small concentrations of detergents.

Basic water treatment processes include: disinfection, sedimentation, coagulation, softening, aeration, adsorption, chemical oxidation, filtration, fluoridation, and stabilization. Disinfection is the killing of disease organisms. Chlorine is generally used because it provides continuous protection against disease organisms for long periods of time. Sedimentation is the process of removing coarse particles of suspended matter from water. During sedimentation, turbidity, color, odor, and taste-causing bacteria are also partially removed. Coagulation is the use of chemicals to remove sediments, turbidity, color-causing bacteria, and organic matter not removed during sedimentation.

Softening is the process of removing principally calcium and magnesium, the causes of hard water. Chemical oxidation, adsorption, and aeration are treatments for taste and odor control. Filtration is a final purification process which removes any suspended particles still present in the water. Fluoridation is the process of adding fluoride. Stabilization treatments are processes for neutralizing any adverse effects on the distribution system of chemicals originally added to improve water quality. Treatment of surface water often begins with sedimentation and coagulation, which allow particles to settle out to clear the water. Ground water is often treated by filtration or aeration to remove iron and manganese.[4]

Alternative courses of action may be considered instead of public treatment processes: 1) treatment by the consumer such as in-home water softeners, 2) acceptance of actual damage such as corrosion and the possibility of disease, and 3) a shift by the consumer to an alternative source such as private wells. However, urban populations have chosen to set standards of water treatment which are designed to eliminate any substantial possibility of disease epidemics. As such, these three alternative courses of action may not be feasible within the urban community, but may be a possibility at the rural-urban fringe.

Quality Standards

The water supplied by public water systems must meet certain standards. The drinking water standards set by officials of the U. S. Public Health Service (PHS) and the American Water Works Association (AWWA) are shown in Table 2. The standards set by the PHS officials consist of mandatory and recommended limits. The standards established by the officials of the AWWA are ideal in terms of protection.

Costs of Chemicals

The amount of chemicals used in treating public water supplies varies with the treatments and the chemical and physical characteristics of the water being treated. Some public supplies are not treated, some are only chlorinated, some require filtration in addition to chlorination, and others are treated for taste and odor control.

The costs of treating water by an identical process vary from city to city because of differences in the composition of the raw water. Even in the same municipality, the treatment costs vary seasonally as the composition of the raw water changes. Table 3 shows the costs of chemicals per million gallons of water treated for several Ohio cities.

WATER COST FUNCTIONS

The general cost function developed for water service in this study is:

$$C = f\,(O_i,\ S_i,\ T_i,\ Z_i) \qquad (1)$$

where C is total costs (total variable, average total, or average variable), O_i are output variables including quantity and quality characteristics, S_i are input water quality characteristics, T_i are treatment variables, and Z_i represent input prices and other factors affect-

[4]For a more detailed discussion of treatment processes, see Cosgrove (1, pages 33-40).

TABLE 2.—Drinking Water Standards.

Quality Criteria	PHS Drinking Water Standards Mandatory	Recommended	AWWA Ideal Water Quality Standards
Physical			
Turbidity		5 Std. Units	0.1 Std. Units
Color		15 Std. Units	3.0 Std. Units
Odor		Threshold Odor	
Taste			
Chemical*			
Alkyl Benzene Sulfonate		0.50	0.20
Aluminum			0.50
Arsenic	0.05	0.01	0.01
Barium	1.00		0.50
Boron	5.00	1.00	
Cadmium	0.01		0.01
Carbon Chloroform Extract		0.20	0.04
Chloride		250.00	
Chromium Hexavalent	0.05		0.01
Copper		1.00	0.20
Cyanide	0.20	0.01	0.01
Fluoride	2.00	0.80-1.30	0.70-1.20
Hardness ($CaCO_3$)			80.00
Hydrogen Ion (pH)			
Iron		0.30	0.05
Lead	0.05		0.05
Manganese		0.05	0.01
Mercury (proposed)	0.005		
Nitrate		45.00	23.00
Phenols		0.001	0.0005
Selenium	0.01		0.01
Silver	0.05		0.02
Sulfate		250.00	
Total Dissolved Solids		500.00	
Zinc		5.00	1.00
Bacteriological			
Coliform Bacteria	1/100 Ml.		0.01/100 Ml.

*With the exception of pH, all figures are in milligrams per liter — mg/l.
Source: Ohio Department of Health (7, pages 24-28), Public Health Service (10), and unpublished material of the Ohio Department of Health.

ing costs. The major reason for selecting cost functions over production functions is to avoid the problem of aggregating quantity and quality dimensions of output. In cost functions, the various dimensions of output can be used as separate variables to determine the impact of each on costs.[5]

TABLE 3.—Costs of Chemicals Used in Water Treatment in Ohio Cities, April 1968.

City	Cost of Chemicals per Million Gallons
Akron	$ 8.43
Alliance	13.48
Ashland	31.46
Bowling Green	31.33
Celina	74.46
Cincinnati	10.52
Cleveland (Division)	4.31
Columbus (Dublin)	25.92
Dayton	13.62
Lima	17.60
Steubenville	15.37
Toledo	12.17
Wooster	25.69

Source: Water Supply Unit, Department of Health.

Costs are comprised of fixed and variable factors. Fixed costs are the per period opportunity and depreciation costs of capital. Variable costs are the per period costs of operating a water firm such as wages, chemical costs, and electricity. Total costs are the sum of fixed and variable costs, while total variable costs include only the variable component. For purposes of this study, average total costs and average variable costs are total costs and total variable costs, respectively, divided by the quantity (gallons) of water. The quality components are not included.

The output variables (O_i) include quantity and quality characteristics. The quantity dimension is gallons of water flow per period. The quality dimensions of water include physical, chemical, and biological characteristics. Various physical quality characteristics are turbidity, color, temperature, odor, and taste. Biological characteristics of water

[5]For further discussion of this point, see Hushak (5, page 6).

are bacteria, viruses, and plankton. Some chemical characteristics and properties are hardness, pH, nitrates, total solids, chlorides, iron, arsenic, pesticides, and radiological materials.

The quality characteristics of input water (S_i) are comprised of the same dimensions as the output water quality characteristics above. These comparable characteristics suggest the simplifying hypothesis that the changes in particular quality characteristics affect costs, and not the levels of these characteristics in the input and output water. For example, costs are affected by the amount of hardnes removed from the water, but are independent of the initial and final levels of hardness.

It may be possible to use the source of water, ground or surface, as a broad measure of input water quality. Surface and ground water sources have largely distinct quality characteristics. Surface sources have more turbidity, lower total solids, more objectionable tastes and odors, and a higher bacterial count. Hardness, alkalinity, and the levels of nitrates, magnesium, and phosphates are higher in ground water. In general, surface sources yield a lower overall quality of input water than ground sources.

Treatment processes (T_i) are the third set of variables which affect costs. Under the hypothesis that it is the changes in quality characteristics which affect costs and to the extent that particular treatments can be identified with changes in particular quality characteristics, the extent to which a treatment process is used is another measure of the changes in a quality characteristic. For example, the amount of softening to which water is subjected is an alternative measure to the change in hardness of water. Although the T_i are considered as a separate set of variables, they are alternative measures of changes in water quality characteristics.

The other factors (Z_i) which affect costs are broadly classified as wage and interest rates (factor prices), the proportion of heavy water users in the system, and the capacity of the system. Differences in wage and interest rates affect the level of cost functions. Further, differences in the relative costs of labor and capital affect the capital-labor ratio, which may also affect the level of cost functions. The existence of a large number of heavy water users, e.g., industry and large apartment complexes, is expected to affect the costs of distributing water since fewer (although larger) water outlets are required per unit of water distributed. Capacity is a measure of the most efficient output level of a water firm. For example, the ratio of capacity to actual output is an indication of the most efficient level of output of a firm relative to its actual output.

The data available for measures of each of these sets of variables are developed in the next section. In the following section, the specific functional forms used to estimate equation 1 are developed.

DATA DEVELOPMENT

Data were collected on 85 cities in Ohio, each serving a population more than 5,000.[6] Six of these observations were deleted because of incomplete data, so 79 cities were included in this study. Cities with their own water supplies serving a population less than 5,000 were excluded because of incomplete data.

Cost data on the 79 cities were collected for the year 1968. April was selected as an average water-using month for 1968 upon the advice of personnel in the Ohio Department of Health. April water use was then multiplied by 12 to obtain an estimate of water production for the year. Data on quality characteristics and physical data were also collected from April 1968, with the exception of labor data which were for the year 1967 (labor data were not available for 1968).

Data were not available on many of the characteristics hypothesized to influence costs in the previous section. These limitations are brought out after the variables are defined. Seasonal variations in the cost function are not analyzed because cost data are available only on an annual basis.

Variable Definitions

The following variables are defined from the available data. The cost variable is:

C = total operating and maintenance cost for 1968.

The output variables (O_i) are:

O_1 = millions of gallons of water produced per year

O_2 = bacteriological quality in the distribution system measured as average number of coliform bacteria per 100 millileters

O_3 = hardness expressed as the quantity of $CaCO_3$ in milligrams per liter or parts per million (p.p.m.)

O_4 = the pH of water after treatment

The input water variables (S_i) are:

S_1 = source of water measured as the percent of water obtained from surface sources

S_2 = raw water turbidity measured in Jackson Candle Standard Units

S_3 = hardness expressed as the quantity of $CaCO_3$ in p.p.m. at the source

S_4 = the pH of the water at the source

S_5 = nitrates in p.p.m. at the source

S_6 = total solids in the raw water in p.p.m. and measures suspended and dissolved solids evaporated at 105° C. and weighed

[6]The Water Supply Unit of the Department of Health, the Auditor's Office of the Department of State, the Ohio Municipal League of Columbus, and the Ohio Municipal Advisory Council of Cleveland supplied the data. Labor data on certain cities were obtained from the 1967 Census of Governments.

The comparable measurements of input and output water hardness and pH allow definitions of the two change variables:

$W_1 = S_3 - O_3$ = change in hardness
$W_2 = S_4 - O_4$ = change in pH

The treatment variables (T_i) are:

T_1 = a continuous variable representing the number of treatment processes used by a city water system
T_2 = disinfection
T_3 = iron removal
T_4 = purification
T_5 = softening
T_6 = stabilization
T_7 = fluoridation

The variables T_2 through T_7 are dummy variables representing broad types of treatments. Each equals 1 (one) when the treatment is used, 0 (zero) otherwise.

Additional factors (Z_i) are:

Z_1 = number of employees per city water system
Z_2 = number of manufacturing plants per city
Z_3 = population density (population served per number of water outlets)
Z_4 = excess capacity (estimated capacity per average daily output)
Z_5 = excess capacity (maximum daily output per average daily output)

Data Limitations

Only operating and maintenance costs are available for all 79 cities. Information on capital costs are available for only 19 cities. A later section presents a brief analysis using capital costs for these 19 cities.

Operating and maintenance costs per year do not correspond exactly with the variable costs of economic theory. If the plants were to shut down, there would still be maintenance costs incurred. Also, some of the cities probably have certain capital cost items included under maintenance and operating costs. For example, cities may include the cash outlay for pipe as a capital cost for a new development, but include it under operation and maintenace outlay for new pipe in an old development.

Data are available on relatively few input and output water characteristics. Further, comparable measures of input and output characteristics are available only for hardness and pH.

The information on treatment processes is limited to whether or not a water system uses a particular process. The only information on the extent of treatments is the cost of chemicals.[7]

The number of employees (Z_1) is the only variable representing other factors of production. Wage and interest rate information were not available. The number of manufacturing plants (Z_2) is used as a proxy for heavy water-using firms. The excess capacity variable Z_4 is based on the operators' estimate of the capacity of the water system. Data on capacity defined as the most efficient output level were not available.

FUNCTIONAL FORM AND STATISTICAL PROCEDURE

Before turning to empirical estimations of cost functions, the problem remains of specifying the mathematical forms of the total and average cost functions from the general form in equation 1. Three total cost models are hypothesized:

$$C = b_0 + b_1 O_1 + \text{other variables} \quad (2)$$

$$C = c_0 + c_1 O_1 + c_2 O_1^2 + \text{other variables} \quad (3)$$

$$C = d_0 + d_1 O_1 + d_2 O_1^2 + d_3 O_1^3 + \text{other variables} \quad (4)$$

Equation 2 is linear in water flow (O_1). Equation 3 is quadratic in O_1 and allows increasing or decreasing marginal costs with respect to O_1, but not both. Increasing and decreasing marginal costs are possible in equation 4, which is cubic in O_1. Other variables designate various subsets of the variables other than O_1 defined in the previous section. These variables are maintained in linear form in all equations.[8]

The forms of the output variables except O_1, the input variables, and the treatment variables impose a severe restriction on the total cost models. These variables have no relationship to the size of the system. For example, the number of treatments only states the number used by the system. The addition of one treatment would be expected to increase costs more for a large system than a small one because the treatment must be used on more water. In the total cost models, however, the additional cost from one additional treatment is constant over the range of the cost function. As such, the coefficients of these variables should be interpreted as an average shift of the cost function for the sample.[9]

The average cost models implied by equations 2, 3, and 4, respectively, are:

$$AC = b_0 \frac{1}{O_1} + b_1 + \text{other variables} \quad (5)$$

[7]There is a problem in linking the extent of treatment to an empirical measure. The cost of chemicals is not appropriate because it is part of operating and maintenance costs. The physical quantity of chemicals was not available. Also, not all treatment processes use chemicals.

[8]Log linear models were tried, but the results were similar to those using equation 3.

[9]The only possible adjustment based on the data available is to multiply these variables by water flow, with the exception of the possible use of chemical costs for extent of treatment. This is the adjustment underlying the average cost models.

$$AC = c_0 \frac{1}{O_1} + c_1 + c_2 O_1 + \text{other variables} \quad (6)$$

$$AC = d_0 \frac{1}{O_1} + d_1 + d_2 O_1 + d_3 O_1^2 + \text{other variables} \quad (7)$$

where AC is average variable cost (C/O_1). In addition, the model:

$$AC = a_0 + a_1 O_1 + a_2 O_1^2 + \text{other variables} \quad (8)$$

is estimated, which is equation 7 under the assumption that $d_0 = 0$. In these models, the output variables except O_1, the input variables, and the treatment variables are used in original form, i.e., they are not divided by water flow. The coefficients of these variables yield shifts in average cost per million gallons of water which is constant over the range of the function.[10]

All cost models are estimated by single equation least squares. To use water flow, quality variables, and other factors as independent variables, it is necessary that they be determined by conditions exogenous to the water firms (2, page 234). All independent variables used in this study are assumed to be predetermined. This assumption is justified for some variables, but is questionable for others.

The source of water, its quality characteristics, and its treatments are determined by the location of the city in relation to the sources of water at that point. These variables are predetermined to the extent that source is beyond the control of the city. The bacteria count of output water is controlled by health standards which are beyond the control of the city water system. Thus, bacteria count and treatments used to remove bacteria are predetermined to the extent that these treatments are based on state standards. Number of manufacturing plants and population density are determined by many factors, including water supply, and thus are largely predetermined. Number of employees is largely predetermined by the size and type of plant and the broader labor market.

The questionable variables are water flow and the pH and hardness of output water. The extent to which these variables are predetermined in the cost function depends on the demand function for water with respect to these variables. If the demand function is inelastic with respect to these variables, then they are predetermined. If there is a price response in the demand function, the assumption that these variables are predetermined is violated and the problem of simultaneous equations bias is present. This bias, if present, is not likely to be serious.

[10]See footnote 9.

ESTIMATED VARIABLE COST FUNCTIONS

This section presents estimates of total variable cost and average variable cost functions, using operating and maintenance costs for the 79 cities in the sample.[11] Table 4 presents characteristics of municipal water supply systems in Ohio during 1968 for the 79 cities, for the cities divided into four groups on the basis of population served, and for the cities divided by source of water.

[11]A brief analysis of cost functions, including capital costs for the 19 cities on which capital information is available, is presented in the next section.

TABLE 4.—Characteristics of Municipal Water Supply Systems in Ohio, 1968.

Population Range and Source (Number of Observations)		Operating Cost per Year $ (000)	Water Output Million Gallons per Year	Average Cost per Million Gallons Water Output	Number of Employees	Number of Treatment Processes	Population Density	Turbidity (Jackson Candle Standard Units)	Hardness Removed (P.P.M.)
Total	Mean	692	4,393.8	229.46	52.8	5.3	3.46	22.4	100.7
79	S. D.*	2,039	15,254.7	84.48	153.6	2.6	.56	36.3	125.8
	Range	33-15,431	142.8-123,549.6	93.70-504.40	1-1,132	0-10	2.14-5.26		
5,000- 9,999	Mean	92	370.3	275.60	5.9	4.3	3.34	18.7	125.6
(23)	S. D.	34	187.9	94.42	3.8	2.6	0.69	36.1	157.0
10,000-19,999	Mean	150	663.9	237.69	11.0	5.5	3.35	21.5	104.0
(28)	S. D.	50	224.4	79.43	5.4	2.7	0.37	33.7	121.4
20,000-49,999	Mean	323	1,731.0	203.31	24.3	6	3.56	33.6	61.4
(14)	S. D.	114	80.0	62.96	12.2	2.4	0.61	47.3	89.0
50,000+	Mean	3,129	21,126.9	163.53	242.3	5.8	3.83	19.1	92.6
(14)	S. D.	4,139	32,056.8	36.38	306.8	2.3	0.49	30.2	108.9
Surface	Mean	1,149	7,444.9	233.29	89.9	7.1	3.54	39.8	65.0
(38)	S. D.	2,838	21,388.7	82.26	214.1	1.2	0.61	43.7	69.7
Ground	Mean	267	1,566.0	225.91	18.6	3.7	3.41	6.3	133.8
(41)	S. D.	529	3,684.0	87.35	33.5	2.5	0.52	15.6	155.0

*S. D. = standard deviation.

TABLE 5.—Regression Coefficients and Related Statistics for Total Variable Cost Functions of 79 Municipal Water Systems in Ohio, 1968.

		Independent Variables*								
Equation	Constant Term	Water Flow O_1	Water Flow O_1^2	Source S_1	Turbidity S_2	Number of Treatments T_1	Number of Employees Z_1	Number of Manufacturing Plants Z_2	Population Density Z_3	$\bar{R}^2$†
2.1	58489.14	131.70**		1147.67**						.981
		(2.12)		(661.85)						
2.2	74360.36	132.28**			1600.55**					.981
		(2.07)			(872.67)					
2.3	4929.62	132.12**				19998.49‡‡				.981
		(2.09)				(12234.85)				
2.4	20800.76	131.78**		763.82***		10468.63***				.981
		(2.13)		(902.15)		(16641.58)				
2.5	—3013.85	130.31**		1095.87‡‡					106092.14††	.982
		(2.23)		(653.27)					(75611.91)	
2.6	67601.27	89.83**		1069.77‡‡				1459.94‡		.983
		(12.30)		(619.40)				(423.38)		
2.7	33081.10	47.42**		—115.76***			8618.15**			.997
		(4.49)		(282.60)			(450.52)			
3.1	—262.76	174.18**	—.0004‡	522.07‡‡						.994
		(3.60)	(.00003)	(381.76)						
3.2	12713.44	174.52**	—.0004‡		461.84***					.994
		(3.61)	(.00003)		(511.98)					
3.3	—23682.54	174.44**	—.0004‡			9082.16***				.994
		(3.58)	(.00003)			(7045.06)				
3.4	—54393.26	174.38**	—.0004‡	502.11***					22561.72***	.994
		(3.75)	(.00003)	(398.65)					(35606,27)	
3.5	8794.14	142.27**	—.0004‡	492.76‡‡				1049.46‡		.995
		(7.78)	(.00003)	(340.51)				(232.91)		
3.6	18267.80	82.33**	—.0001‡	119.36***			6525.66**			.997
		(9.48)	(.00003)	(253.42)			(646.46)			

*Standard errors of regression coefficients are in parentheses.
†Significant at the .01 level unless otherwise indicated.
‡Significant at the .05 level in a two-tail test.
**Significant at the .05 level in a one-tail test.
††Significant at the .10 level in a two-tail test.
‡‡Significant at the .10 level in a one-tail test.
***Not significant in the appropriate test.

The population served ranged from 5,000 to 1.8 million in the 79 cities. The four subgroups by population served are 23 cities each serving 5,000 to 9,999 people, 28 cities each serving 10,000 to 19,999, 14 cities each serving 20,000 to 49,999, and 14 cities each serving a population more than 50,000. The number of observations within each subgroup indicates that each size group is adequately represented, although the numbers of observations are somewhat less for the two largest subgroups. By source, 38 cities obtain water from surface sources and 41 cities from ground sources.[12] The mean operating costs, water output, and number of employees for the total sample, the more than 50,000 population group, and the surface subsample are dominated by the large cities in the sample.

Total Variable Cost Estimates for the Combined *79* Cities

Estimates of total variable cost functions for the 79 water systems in the sample are presented in Table 5. Equations 2.1 to 2.7 are linear models based on equation 2. Equations 3.1 to 3.6 are quadratic in water flow, based on equation 3. Other variables are not included in these equations as they had little effect on the estimates, i.e., their coefficients were not significantly different from 0 at the .10 level in either model and they had little effect on the coefficients of other variables in the equations, especially on the coefficients of O_1, O_1^2, S_1, S_2, or T_1.[13]

As compared to the linear equations, the quadratic equation estimates in Table 5 have a higher $\overline{R}^2$ (adjusted R_2), a higher marginal cost of water flow, and reduced coefficients on all other variables used in the equations. On the basis of $\overline{R}^2$, it is concluded that the quadatic model is better than the linear model. This conclusion is tentative because the results could easily be caused by the lack of data on several factors (treatment intensity, for example), resulting in a specification error. However, conclusions from total cost equations are based on the quadratic models.

In equations 3.1 to 3.4, the marginal cost of water flow at the mean water flow of the sample is approximately $170 per million gallons. Marginal cost declines as water flow increases. Using equation 3.1 and the mean water flows of the four groups of cities in Table 4, the marginal cost per million gallons is $173.88 at the mean of the 5,000 to 9,999 group, $173.65 for the 10,000 to 19,999 group, $172.80 for the 20,000 to 49,999 group, and $157.28 for the more than 50,000 group. Although there are economies of scale from increased size, the possibilities of cost reductions from larger water systems are limited except where a small city can utilize the water services of a city with a population of more than 50,000. As compared to the quadratic equations, the marginal cost of water flow is about $130 per million gallons in the linear equations 2.1 to 2.5.

In equation 3.1, the coefficient of source is positive and significant. Each additional 1 percent of water obtained from surface sources costs $522. A water system using all surface water would have variable costs of $52,207 in excess of a system using all ground water. The coefficients of turbidity and number of treatments are positive but not significant in equations 3.2 and 3.3. In contrast, the coefficients of source, turbidity, and number of treatments in the linear equations 2.1 to 2.3, respectively, are all positive, significant, and more than double their magnitude in equations 3.1 to 3.3. When more than one of these variables is put into an equation, neither is significant, as in equation 2.4. It should be recalled that the form of these variables imposes a constant shift on the cost function; they do not allow the shift to vary as the size of the water system varies. As such, the coefficients are very crude measures of the cost reductions from improvements in input water quality.

Population density has positive coefficients in equations 2.5 and 3.4, but is significant only in the linear equation. It was expected that higher population densities would reduce the costs of distributing water. However, Z_3 appears to be related to the fixed cost component of water systems since its major impact on equations 2.5 and 3.4 is a reduction in the constant terms. The extent of capital costs in operating and maintenance expenses is unknown.

The number of manufacturing plants in equations 2.6 and 3.5 was also expected to have a negative coefficient as a proxy for the number of large volume water users. The coefficients of Z_2 are positive, significant, and reduce the coefficients of O_1 in both equations. The number of employees with positive significant coefficients in equations 2.7 and 3.6 reduces the coefficients of O_1 by more than Z_2 reduces them. In addition, the coefficients of O_1^2 and S_1 are reduced in equation 3.6, while the coefficient of S_1 becomes negative in equation 2.7. Both Z_1 and Z_2 are highly correlated with O_1, with simple correlations of .99 and .98, respectively, and are probably acting as

[12] Six cities use both surface and ground sources. They are classified as surface or ground in Table 4 on the basis of the source from which the most water is obtained.

[13] A quadratic model with number of treatments (T_1) times water flow (O_1) as an independent variable was estimated. The coefficients of O_1 and O_1^2 were changed little from those of equation 3.3 in Table 5. Also, an attempt was made to estimate the cubic function. When the cubic term entered, the quadratic term was forced out of the equation by the regression program. The resulting equation was similar to the corresponding quadratic equation. Finally, the set of dummy treatment variables was tried as an alternative to T_1. The F-ratio on the set was not significant.

TABLE 6.—Total Variable Cost Functions for Municipal Water Systems in Ohio by Source, 1968.

			Independent Variables*					
			Water Flow			Number of Treatments	Hardness Removed	
Equation	Water Source	Constant Term	O_1	O_1^2	Turbidity S_2	T_1	W_1	$\bar{R}^2$†
3.7	Surface	61971.65	180.54** (4.73)	—.00045‡ (.00004)			—502.83*** (452.94)	.996
3.8	Surface	30864.76	181.17** (4.84)	—.00045‡ (.00004)	—115.87*** (735.37)			.995
3.9	Surface	34540.25	182.30** (4.66)	—.0005‡ (.00004)		—45427.44*** (26495.26)		.996
3.10	Ground	35877.62	127.09** (11.94)	+.00067*** (.00055)			162.81** (79.82)	.978
3.11	Ground	51525.43	126.52** (12.37)	+.00075*** (.00057)	933.32*** (816.37)			.971
3.12	Ground	11116.15	121.73** (11.48)	+.001†† (.0005)		13668.74** (4744.09)		.980

*See footnotes to Table 5.

measures of size rather than as proxies for relative intensities of labor and heavy water users.

Total Variable Cost Estimates by Source

The quality of input water varies, depending on whether a city obtains its water from a surface or a ground source. The cost structure may vary depending on the source of water. The sample is divided on the basis of Table 4. Total variable cost function estimates are presented in Table 6 for each subsample. The estimated equations are very different; a residual sum of squares test for each pair, equations 3.7 and 3.10, 3.8 and 3.11, 3.9 and 3.12, yielded significant F-ratios at the .05 level.

There are two reasons for the differences. First, the underlying production functions may differ. Second, and probably the cause of most of the differences, the data prevent full specification of the model. The interaction of turbidity, number of treatments, and hardness removed differs between the surface and ground equations. In the surface equations, the coefficients of these variables are all negative, which is probably the reason why the water flow coefficients are larger in magnitude than those for comparable equations in Table 5. This is not unexpected, since water systems with surface sources have input water which is of relatively uniform poor quality.

On the other hand, the coefficients of S_2, T_1, and W_1 in the ground equations are large, positive, and significant with the exception of S_2. The major treatment problem with ground water is the removal of hardness, and T_1 and W_1 may be more accurately removing these costs from the water flow variables in the ground equations than in either the surface equations or the combined equations in Table 5. If true, then the coefficients of the water flow variables of the surface and total equations are biased upward; they include costs resulting from variations in input water quality. The ground equations also show constant to increasing marginal costs. This is not disturbing since the cities with ground sources are relatively small, with the exception of Dayton.[14]

Average Variable Cost Estimates for the Combined 79 Cities

Average variable cost function estimates for the 79 cities are presented in Table 7. Equations 6.1 to 6.7 are estimates based on equation 6, and equations 8.1 to 8.6 are based on equation 8.[15] Equations 6.1 to 6.7 yield better statistical estimates than equations 8.1 to 8.6, and most of the discussion is based on them.

The water flow coefficients of equations 6.1 to 6.7 are broadly consistent with the water flow coefficients of the quadratic total cost functions in Table 5. The constant terms are smaller than the coefficients of O_1 in equations 3.1 to 3.6, which they should equal. One conclusion of the results presented in Table 6 was that the linear terms in the combined total cost equations of Table 5 are biased upward. Also, the constant terms are more subject to change when other variables are used in the equations. Finally, the other variables become changes per million gallons in the average cost functions as compared to changes per system in the total cost equations. They

[14]Equations using number of employees were estimated, but yielded erratic results.

[15]Estimates of equations 5 and 7 are not presented. The results from equation 5 differed little from those of equation 6 in Table 7. Problems similar to those for the cubic total cost function, equation 4, were encountered in attempts to estimate equation 7; the inverse variable dominated the quadratic variable.

TABLE 7.—Regression Coefficients and Related Statistics for Average Variable Cost Functions of 79 Municipal Water Systems in Ohio, 1968.

Equation	Constant Term	Water Flow O_1	Water Flow $1/O_1$	Water Flow O_1^2	Source S_1	Turbidity S_2	Number of Treatments T_1	Hardness Removed W_1	Number of Manufacturing Plants Z_2	Population Density Z_3	Employees per Million Gallons Z_1/O_1	$\bar{R}^2$†
		Independent Variables*										
6.1	153.09	—.00063***	34918.41**		.39**							.36
		(.00053)	(5623.95)		(.16)							
6.2	165.31	—.00050***	32403.12**			.46**						.35
		(.00053)	(5507.91)			(.21)						
6.3	98.68	—.00058***	35755.93**				13.48**					.48
		(.00047)	(4967.35)				(2.68)					
6.4	99.69	—.0021***	35501.78**				13.42**		.054***			.48
		(.0029)	(5012.46)				(2.69)		(.099)			
6.5	116.46	—.00055***	35935.08**				1362**			—5.51***		.48
		(.00051)	(5013.64)				(2.72)			(13.28)		
6.6	101.62	—.00052***	33750.29**				11.72**	.10‡‡				.50
		(.00047)	(5072.78)				(2.87)	(.06)				
6.7	81.41	—.00045***	30018.92**				9.91**				2828.92**	.54
		(.00045)	(5076.17)				(2.80)				(928.61)	
8.1	233.75	—.0052‡		.000000032‡	.20***							.08***
		(.0018)		(.000000015)	(.19)							
8.2	232.71	—.0052‡		.000000032‡		.48**						.11
		(.0018)		(.000000014)		(.25)						
8.3	184.33	—.0054‡		.000000036‡			11.30**					.19
		(.0017)		(.000000015)			(3.33)					
8.4	185.89	—.012‡		.000000039‡			11.25**		.16***			.20
		(.0041)		(.000000015)			(3.31)		(.12)			
8.5	180.96	—.0052‡		.000000034‡			8.21**	.18**				.25
		(.0016)		(.000000014)			(3.43)	(.07)				
8.6	134.47	—.0041‡		.000000028‡			6.12**				4562.37**	.35
		(.0015)		(.000000013)			(3.20)				(1027.71)	

*Standard errors of regression coefficients are in parentheses.
†Significant at the .01 level unless otherwise indicated.
‡Significant at the .05 level in a two-tail test.
**Significant at the .05 level in a one tail test.
††Significant at the .10 level in a two-tail test.
‡‡Significant at the .10 level in a one-tail test.
***Not significant in the appropriate test.

are expected to have a stronger impact in the average cost equations.

The coefficients of O_1 in equations 6.1 to 6.7 of Table 7 are negative, but are larger in magnitude and are not significantly different from 0 as compared to the coefficients of O_1^2 in Table 5. The coefficients of the inverse term are larger than the constant terms in equations 3.1 to 3.6. In equation 6, the constant component of total variable costs is estimated by the coefficient of the inverse term, and averages about $35,000 for the equations in Table 7.

As a result of total cost estimates, it was concluded that marginal cost reductions from larger water systems were small. However, the fixed cost component was not considered because it was unstable. With a stable estimate of the fixed cost component from equation 6, which is large, the implications for cost reductions from expansion are changed from the spreading of fixed costs.

Using 35,000 as the coefficient for the inverse term and —0.0006 as the coefficient of O_1, the rates of changes in average costs for the four groups of cities at the mean water flow in Table 4 are $0.26 per million gallons for the 5,000 to 9,999 group, $0.08 for the 10,000 to 19,999 group, $0.01 for the 20,000 to 49,999 group, and $0.0007 per million gallons for the more than 50,000 group. Small water systems can reduce average costs by spreading the rather large fixed component of operating expenses.

The large fixed cost component also explains the relatively poor results of the quadratic estimates, equations 8.1 to 8.6, in Table 7. The quadratic estimates yield results similar to the inverse estimates for the larger cities, but they cannot approximate asymptotic behavior as sharp as that implied by the estimates of equation 6.

Source, turbidity, and number of treatments are again substitute measures of the quality of input water. As changes per million gallons, these variables are statistically more significant than they were in the total cost equations. The change in average costs from an additional treatment in equations 6.3, 6.4, and 6.5 is about $13.50 per million gallons, which compares with $11.30 in equations 8.3 and 8.4.

The number of manufacturing plants has an unexpected sign in equations 6.4 and 8.4, is not significant in either equation, but does change the magnitude of the coefficients of O_1 in both cases. The coefficient of population density has the expected sign in equation 6.5 as compared to the total cost function, but is not significant and has little effect on the rest of the equation (the comparable quadratic function yielded a positive insignificant coefficient). Hardness removed is positive and significant in equations 6.6 and 8.5, with costs of $0.10 and $0.18 per million gallons per unit removed, respectively. The major effect of W_1 is to reduce the coefficients of T_1, as expected, since removal of hardness (softening) is one type of treatment.

In equations 6.7 and 8.6, the coefficients of labor per million gallons are positive and significant. The coefficients are the marginal costs of an additional employee, the same as in the total cost models. In equation 6.7, the labor coefficient of $2,829 appears small, but this probably reflects an interrelationship between labor and treatments. Although T_1 is a proxy for input water quality, it is also a general measure of inputs, including labor, for water treat-

TABLE 8.—Average Variable Cost Functions for Municipal Water Systems in Ohio by Source, 1968.

Equation	Source	Constant Term	Independent Variables* — Water Flow O_1	Water Flow $1/O_1$	Water Flow O_1^2	Number of Treatments T_1	Employees per Million Gallons $Z_1O/_2$	$\bar{R}^2$†
6.8	Surface	136.34	—.00031*** (.00046)	48262.26** (8152.03)		4.75*** (5.90)		.53
6.9	Ground	104.31	—.0011*** (.0029)	27245.43** (6655.02)		18.29** (3.90)		.52
6.10	Surface	129.81	—.00031*** (.00047)	45632.86** (11209.12)		4.54*** (6.01)	670.49*** (1932.07)	.51
6.11	Ground	79.02	—.00071*** (.0026)	23901.61** (6192.80)		13.41** (3.95)	3421.78** (1187.91)	.60
8.7	Surface	180.92	—.0043†† (.0024)		.00000003*** (.00000002)	3.71*** (11.13)		.11***
8.8	Ground	190.57	—.036‡ (.010)		.0000015*** (.0000051)	19.0** (4.31)		.41

*See footnotes to Table 7.

ments. More encouraging is that labor has a relatively much smaller impact on the water flow coefficients in the average cost equations than it had on the total cost estimates.[16]

Average Variable Cost Estimates by Source

The equations in Table 8, where cities are separated by source of water, again show differences in the cost function. In equation 6.8, the coefficient of the inverse term is about 80 percent larger than the coefficient in equation 6.9. The asymptotic slope coefficients (of O_1) are not significant, but the coefficient for ground source cities is of greater magnitude. This is inconsistent with the total cost results for ground source cities where the coefficient of O_1^2 was positive, although not significant. However, the major difference is a large and significant coefficient for number of treatments for ground source cities as compared to a small, insignificant one for surface source cities. This is consistent with the results of the total functions, with the exception that the coefficient of T_1 was negative for the surface group. Labor is not significant and has little effect on equation 6.10, but is significant in 6.11 and reduces all other coefficients for the ground source cities.

Summary

In summary, several points can be made from the total and average variable cost estimates. First, the marginal costs of water flow decline with increasing system size. However, the rate of decline is probably too small to make the consolidation of water systems attractive unless the size of the consolidated system is several times as large as the individual systems.

Second, the average cost estimates of equation 6 indicate a rather large fixed component of operating expenses. If true, then small systems can realize larger cost reductions from consolidation by the spreading of this fixed component.

Third, water quality does matter, although specific quality components have not been isolated. The more significant results of water quality measures, e.g., number of treatments, for ground source cities probably result from a larger variation in the variables for these cities. Most surface source systems use six to eight basic treatment processes, while ground source cities use one to six.

Fourth, many specification problems remain. For example, it is premature to conclude that surface and ground source cities have different cost functions. The differences in estimated water flow coefficients are in part due to a better isolation of treatment costs for ground source cities. Remaining differences may be eliminated by better control of water quality and factor price variables.

Finally, some general speculations about the magnitudes of the water flow coefficients are made. The fixed component of operating expenses is probably not as large as the $35,000 estimated in equations 6.1 to 6.7, but closer to $35,000 than to the constant terms of the total cost equations 3.1 to 3.6. A linear component (the coefficient of O_1 in equation 3 and the constant term in equation 6) of $100 to $140 appears reasonable if all factors could be controlled. No general bias appears probable for the quadratic coefficients, i.e., values of —0.0004 to —0.0006 at least appear to be of the right order of magnitude.

TOTAL COST ESTIMATES

This section presents estimates of total and total average cost functions for the 19 cities for which capital data are available. Capital costs include costs of equipment, land, buildings, and systems. It is assumed that capital costs are adjusted to replacement value for the year 1968.

The accuracy of the capital cost data can be questioned for two reasons. First, some of the capital cost data are probably included in operating and maintenance costs. Second, it is difficult for the cities to evaluate the capital structure of their water systems. A system may be in the process of expansion or it may have been expanded or improved one or more times in the past.

Three total cost variables are used. One variable is operating and maintenance costs as used for the total sample. Comparisons are made between this subsample and the total sample. The second variable is operating and maintenance costs per year plus the annual depreciation costs of the water systems, using a 20-year economic life (5 percent straight line depreciation).[17] The third variable is operating and maintenance costs per year plus the annual depreciation costs of the water systems plus 5 percent opportunity costs on the invested capital.

Land values are not included in capital costs for depreciation as land does not depreciate in value, but probably increases. However, the value of land is included in the capital costs to obtain the 5 percent opportunity costs.

Mean average operating and maintenance costs are $229.00 per million gallons for the 19 cities. This compares to mean average costs of $229.46 per mil-

[16]This admittedly confusing state of affairs with respect to labor (and other factors of production) cannot be resolved with the current set of data. From its behavior in the total and average cost equations, it is not possible to determine whether labor is partially resolving a specification problem or creating a multicolinearity problem. It is probably doing both. Wage rates and other factor prices are needed for a better empirical specification.

[17]A 20-year economic life was selected in a conversation with Robert Shoup, Ohio Department of Health, on March 9, 1971. The physical life of water systems is probably somewhat longer, but due to technology and growth, the economic life is less than the physical life.

lion gallons for the total group of 79 cities in Table 4. Mean average operating and maintenance costs plus depreciation ranged from \$131.40 to \$865.56 per million gallons, with the mean value for the 19 cities being \$392.21 per million gallons. The mean average operating and maintenance costs plus depreciation plus opportunity costs are \$592.10.

Total cost function estimates for the 19 cities are presented in Table 9. Equations 3.13 to 3.18 are total cost equations and equations 6.12 to 6.14 are average cost equations. In equations 3.13 and 3.14, operating and maintenance costs are the dependent variables. As compared to the total sample results, all coefficients for the 19-city subsample are of greater magnitude. Marginal costs of water flow are greater, but decline more rapidly. Marginal costs at the mean water flow of the 19 cities (6,254 million gallons) are \$177.80 per million gallons in equation 3.13, as compared to \$170.03 per million gallons (mean flow of 4,394 million gallons) in equation 3.3 of Table 5. The costs of an additional treatment are about \$29,000 in equation 3.13, as compared to \$9,000 in 3.3.

Results using the product variable T_1O_1 are presented because they yield more significant coefficients than T_1. The coefficient of T_1O_1 is the cost per million gallons of an additional treatment (\$0.38 in equation 3.14). The main effect of T_1O_1 is to increase the magnitude of the coefficients of O_1^2; the simple correlation between O_1 and T_1O_1 is 0.98.

Operating and maintenance costs plus capital depreciation are the dependent variables in equations 3.15 and 3.16. The addition of depreciation increases the coefficients of O_1 by about \$300, of O_1^2 by a factor of 5, of the treatment variables by a factor of 4. Marginal costs at the mean water flow are \$434 in equation 3.15, while the costs of an additional treatment are about \$120,000.

In equations 3.17 and 3.18, the dependent variables are operating and maintenance costs, depreciation, and opportunity costs. Marginal costs are \$728 at the mean water flow and treatment costs are about \$260,000 per treatment in equation 3.17.

In the average cost equations, the dependent variables in 6.12 are operating and maintenance costs, depreciation is added in 6.13, and opportunity costs in 6.14. The F-ratios of equations 6.13 and 6.14 are not significant. The results of equation 6.12 are broadly consistent with 3.13 and 3.14, as well as earlier average cost equations for the total sample. Equations 6.13 and 6.14 show increases in marginal costs of water flow and treatments, but the lack of significance in the equations precludes any conclusions about magnitudes.

TABLE 9.—Total and Average Cost Functions for 19 Municipal Water Systems in Ohio, 1968.

		Independent Variables*					
		Water Flow			Number of Treatments		
Equation	Constant Term	O_1	O_1^2	$1/O_1$	T_1	T_1O_1	$\bar{R}^2$†
			Total Cost Models				
3.13	—122584.27	196.73** (29.32)	—.0014*** (.0010)		29135.25*** (28097.40)		.97
3.14	—2374.57	193.08** (28.00)	—.0022†† (.0012)			.38‡‡ (.25)	.97
3.15	—1881600.78	466.32** (116.89)	—.0073†† (.0042)		120714.42*** (120320.74)		.86
3.16	—17274.39	524.71** (132.84)	—.012†† (.0060)			1.76‡‡ (1.22)	.84
3.17	—4748001.45	829.37** (270.01)	—.015*** (.0091)		261275.15*** (277928.23)		.75
3.18	—34342.06	856.33** (241.01)	—.023*** (.014)			3.10‡‡ (2.21)	.78
			Average Cost Models				
6.12	143.63	—.0032*** (.0021)		1932.89‡‡ (1116.57)	15.41** (7.33)		.31
6.13	280.72	—.00050*** (.00050)		2290.72*** (2594.97)	25.52‡‡ (17.03)		.06***
6.14	418.32	—.00066*** (.0082)		2608.51*** (4382.39)	35.52*** (28.75)		—.03***

*See footnotes to Table 7.

TABLE 10.—Marginal and Average Variable Costs of Water Flow at the Mean Water Flows of the Four Groups of Cities.

Population Range*	Mean Water Flow Million Gals. per year	Marginal Costs per Million Gals. (3.1)†	Changes in Marginal Costs per Million Gals. (3.1)†	Average Variable Costs per Million Gallons (6.1)†	Changes in Average Variable Costs per Million Gals. (6.1)†
5,000-9,999	370.3	173.88	—.0008	247.16	—.26
10,000-19,999	663.9	173.65	—.0008	205.27	—.08
20,000-49,999	1,731.0	172.80	—.0008	172.17	—.01
More than 50,000	21,126.9	157.28	—.0008	141.43	—.0007

*The size groups are those used in Table 4.

†Equations from which figures are computed. Equation 3.1 is in Table 5 and 6.1 is in Table 7.

The estimates of Table 9 yield one important conclusion. If the capital cost data are of correct order of magnitude, then the capital costs of water flow and treatment are larger than the variable costs on which this study is based. Further study including capital costs is needed. The very preliminary results of this analysis indicate that cost functions including capital cost behave similarly to those of the previous section based on operating and maintenance costs, with considerably larger coefficients.

SUMMARY AND CONCLUSIONS

The purpose of this study is to estimate cost functions for city water systems. The conceptual model is:

$$C = f(O_i, S_i, T_i, Z_i) \qquad (1)$$

where the dependent variables are capital and/or operating and maintenance costs. Operating and maintenance costs are available for 79 cities, capital costs are available for only 19 cities. Each independent variable in the model is classified as an output variable (O_i), input variable (S_i), treatment variable (T_i), or other variable affecting cost (Z_i). The variables included in the model are chosen on the basis of economic theory, a knowledge of the industry, and data availability. The water output variables are divided into quantity and quality variables. Water flow represents the quantity dimension. The quality dimensions are represented by hardness, pH, and bacteria count.

The water input variables are source of water and quality variables such as turbidity, hardness, pH, nitrates, and total dissolved solids. Of the above quality variables, the input and output measures of hardness and pH measure similar characteristics. From these measures, two new variables are formulated: the change in hardness and the change in pH.

The third set of variables are water treatments. Treatments are represented by number of treatments and dummy variables representing broad types of treatments. Other factors hypothesized to affect cost are number of employees, number of manufacturing plants, population density, and capacity of the systems.

Total and average cost models are estimated by ordinary least squares. All models are arithmetic. Total cost models are linear, quadratic, and cubic in water flow, but linear in all other variables. The average cost models are derived from the total cost models.

The total variable and average variable cost functions indicate that marginal costs of water flow decline with increasing system size. However, the rate of decline is probably too small to make the consolidation of water systems attractive unless the size of the consolidated system is several times as large as the individual systems. In the quadratic equations, the marginal costs at the mean water flow are about \$170 per million gallons. The marginal costs and changes in marginal costs of water flow at the mean water flows of four size groups of cities are presented in Table 10.

The average cost equations indicate a rather large fixed component of operating expenses. Small water systems can also realize cost reductions from consolidation by the spreading of this fixed component. Average variable costs and changes in average variable costs for the four groups of cities are shown in Table 10. Although the magnitude of average cost varies depending on other variables in the equations, the rates of change of average costs are stable.

When the observations are separated by source of water, the cost functions of the two groups differ. The differences between the surface and ground equations may be due either to specification problems from the data or to differences in the cost structures. Separation by source of water suggests that the marginal cost coefficients of water flow for the combined 79 cities estimated from the quadratic total cost models are probably too large in magnitude. Marginal costs of $100 to $140 per million gallons appear reasonable. Estimates of marginal costs outside of this range are probably due to inability to control variations in water quality and input prices. More study is needed before it can be concluded that surface and ground source cities have different cost functions.

The estimated capital cost functions for the 19 cities indicate significant increases in marginal costs and that marginal costs of water flow decline with increasing system size. However, further information on capital costs is needed to obtain better estimates of total cost functions.

Measures of the impact of quality on costs suggest that the use of surface water is more expensive in terms of operating and maintenance costs. The source and turbidity variables have positive coefficients. Number of treatments indicates that each additional treatment costs the cities approximately $9,000 per year. Surface source cities use more treatments.

As compared to the total sample results, when the cities are separated by source of water, the surface source cost functions show insignificant impacts from water quality variables, but increased marginal costs of water flow. The ground source cost functions show larger impacts from water quality factors and lower marginal costs. These results are caused in part by lack of variation in water quality variables for surface source cities. These results are the basis of the conclusion that marginal costs of water flow are over-estimated in the combined and surface source equations, while the costs of changing water quality are under-estimated.

The results of this study should be viewed as exploratory. The most confidence can be placed in the conclusion that cost reductions can be realized from water system expansion. Small decreases in marginal costs result from expansion. Smaller systems can also take advantage of the spreading of a relatively large fixed component in operating and maintenance costs. On the other hand, the magnitude of the marginal costs of water flow and the magnitude of the costs of changing water quality are open to question. Better information on water quality characteristics is needed for a better empirical specification of the cost function.

More generally, the costs of producing water for consumption need to be linked to the costs of treating waste water. As water use increases, the time allowed for natural purification declines. The tradeoffs between waste water and consumption water treatments are becoming more important. In this broader framework, the demand for water quality from other uses, such as recreation, also needs to be considered.

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